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THE IMPORTANCE OF INTEGRATED PROJECTS IN HISTORIC CONSERVATION EDUCATION

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Abstract. *The Erasmus Mundus Advanced Masters in Structural Analysis of Monuments and Historical Constructions (SAHC) is a unique European program. It is a Master Program jointly run by four Universities on the conservation of architectural heritage structures, with the goal of producing an international platform of competence.*

The educational objective of SAHC is to offer an advanced engineering program on the conservation of structures, with a focus on cultural heritage buildings. The program is composed of eight units (SA-1 through SA-8). SA-7 is the Integrated Project which is a project-based unit that includes group projects to solve real engineering problems with heritage structures.

This paper will describe and demonstrate the importance of the integrated project as part of the overall education of emerging engineering professionals in the field of conservation of the built cultural heritage. While successful in Europe, the SAHC program with its Integrated Project could be used as a model for other countries to implement a quality education program for engineers in the conservation of heritage structures.

1 INTRODUCTION

"Structural engineering is the art of molding materials we do not wholly understand into shapes we cannot precisely analyze, so as to withstand forces we cannot really assess, in such a way that the community at large has no reason to suspect the extent of our ignorance." This is a modified version of a quote whose origin is attributed to a 1967 British textbook, *Structural Analysis Volume One*, by Dr. E. H. Brown [1]. The statement highlights the difficulty of educating (civil-structural) engineers in a highly technical society. While we believe we know so much about how structures perform, we are still learning about the precise working of the materials and random forces of nature. However as the defenders of public safety, we must endeavor to make the built environment safe for the general public.

We believe that there has been structural engineering since man began building. Most design and construction from the ancient through medieval periods was carried out by master builders or artisans (stone masons and carpenters). They had no theory of structures; they relied upon intuition, trial-and-error, and then empirical evidence of success. Structures were often repetitive, and improvements were generally incremental. There are no records or calculations of the first analyses of structural members or the behavior of materials. The science of engineering did not advance much until the Renaissance and then the Industrial Revolution [2]. Now we operate in the computer world.

Where does this leave us in educating the future engineers that will master the modern structures of the world? Better yet, what about the repair and maintenance of the existing structures that have survived countless decades or millennia that form the fabric of our culture? How are we to understand the performance of these wonderful heritage structures and protect them for future generations? The answer always lies in education! That takes us to the Erasmus Mundus Advanced Masters in Structural Analysis of Monuments and Historical Constructions (SAHC), a unique engineering education program offered in Europe by a consortium of universities. Having about 50% of the students from outside Europe, SAHC is a European Master Program specifically targeted to the conservation of cultural heritage monuments and buildings. While internationally there are numerous conservation programs for architects and conservators, SAHC is unique in its emphasis on the engineering of heritage structures.

The consortium institutions that offer the SAHC program are: University of Minho (Portugal); Czech Technical University (Czech Republic); Technical University of Catalonia (Spain); University of Padova (Italy); and Institute of Theoretical and Applied Mechanics of the Academy of Sciences (Czech Republic). Prof. Paulo B. Lourenço of the University of Minho is the overall SAHC program coordinator.

"Erasmus Mundus is a co-operation and mobility programme in the field of higher education. It aims at enhancing the quality of European higher education and promoting dialogue and understanding between people and cultures through cooperation with third countries. In addition, the programme contributes to the development of human resources and the international cooperation capacity of higher education institutions in third countries by increasing mobility between the European Union and these countries. The name of the programme comes from Desiderius Erasmus Rotterdamus, a 15th-century Dutch humanist and theologian who studied in the best monastic schools throughout Europe. In his days, he was known as one of the most brilliant students of the time. "Mundus" is the Latin word for "world" and thus stands for the programme's global outreach.

The programme's specific objectives are to: (a) promote structured cooperation between higher education institutions and enhance the quality of European higher education with a distinct European added value, attractive both within the European Union and beyond its borders;

(b) contribute to the mutual enrichment of societies by developing the qualifications of women/men so that they possess particular skills, are open-minded and internationally experienced. This is achieved through promoting mobility for the most talented students and academics from third countries towards the European Union and vice versa; (c) contribute towards the development of human resources and the international cooperation capacity of higher education institutions in third countries through increased mobility streams between the European Union and those countries; (d) improve accessibility and enhance the profile and visibility of European higher education in the world as well as its attractiveness for third country nationals and citizens of the European Union." [3]

SAHC addresses the conservation of structures, through preservation and restoration with a focus on the built cultural heritage. By its name, the program emphasis is on analysis and diagnostics of monuments and historical constructions. However, historical pertains to age and is not limited to social importance or a specific event in time. The program is composed of eight units, SA-1 through SA-8.

- SA-1: History of Construction and of Conservation
- SA-2: Structural Analysis Techniques
- SA-3: Seismic Behaviour and Structural Dynamics
- SA-4: Inspection and Diagnosis
- SA-5: Repairing and Strengthening Techniques
- SA-6: Restoration and Conservation of Materials
- SA-7: Integrated Project
- SA-8: Dissertation

Through these units, the students are introduced to general methodological or philosophical concepts (history of construction and restoration in addition to principles and methodology of conservation). The majority of the emphasis is on engineering-oriented issues (experimental techniques, computer modeling, structural analysis, seismic behaviour and structural dynamics, repair and strengthening techniques, surveying, monitoring). SA-7, Integrated Project is a project-based unit that solves real engineering problems. SA-8 is the program dissertation to develop further research and/or professional competence in the field of conservation and restoration of cultural heritage structures.

This paper describes the SA-7, Integrated Project of SAHC. Using examples from actual classes in Portugal and the Czech Republic and responses from student surveys, it will demonstrate the importance of the integrated project as part of the overall education of emerging engineering professionals in the field of conservation of cultural heritage. While successful in Europe, the SAHC program and the Integrated Project could be used as models for other countries to implement a similar quality education program for engineers.

2 ERASMUS MUNDUS SAHC

The one-year master's program has 60 credits using the European Credit Transfer and Accumulation System (ECTS). ECTS is a European "tool that helps to design, describe, and deliver study programmes and award higher education qualifications. The use of ECTS, in conjunction with outcomes-based qualifications frameworks, makes study programmes and qualifications more transparent and facilitates the recognition of qualifications" [4]. Courses are based upon "learning outcomes" or what students are expected to know, understand and be able to do plus workload (the time students typically need to achieve these outcomes). Each learning outcome is expressed in credits, with a student workload ranging from 1,500 to 1,800 hours for a year or approximately 25-30 hours of work per credit.

The SAHC program began in 2007 with European Commission funding through 2016. Coordinated through the University of Minho in Portugal [5], the coursework is conceptually identical for all but only two universities host courses in an academic year (Portugal and the Czech Republic hosting during 2013-2014 and odd numbered years, while Italy and Spain hosting 2014-2015 and even years). Students take their coursework in one country and then move to a second country for their dissertation. Therefore, they are exposed to two universities, two cultures, and ultimately receive two degrees. After the completion of the first course unit, the students meet together for an Integration Week around Barcelona (Poblet Monastery/ L'Espluga de Francolí), Spain where, among other activities, they (a) prepare an international dinner with specialties from their own countries, (b) take two extra courses in "Business Presentations & Communication Skills" and "Leadership & Team Management Skills", (c) have technical visits, (d) interact with alumni, (e) have touristic and open air activities, and (f) hear about research, innovation and job searching.

Applicants to the program come from over 50 countries. The admission requirements for students are a good quality degree in Civil Engineering or equivalent qualifications. Architects wishing to apply must have a solid background in structures. Typically, students are expected to have a higher education degree with four or five years.

The program language is English and students must demonstrate proficiency through standardized tests. Approximately 30 applicants are selected per year from a pool of several hundred. The ranking is based on the following criteria: (a) previous higher education studies and the quality of the institutions; (b) relevant work experience if they have been previously employed in a technical field; (c) recommendation letters; (d) motivation and thesis outline (applicants must state their interest in the program and suggest a potential thesis project); and (e) additional information (publications, etc.). For many students, this program is a second master's; for other students, it is their first graduate degree. Several students have had previous work experience.

3 ENGINEERING EDUCATION

For the success of the Erasmus Mundus SAHC program, we must first consider the overall education of the engineering students that apply. Based upon informal interviews and a review of backgrounds of student applicants to the SAHC program, we find that the applicants: (a) come primarily from a traditional civil engineering background and have had an emphasis in structural engineering. Some possess an architecture degree but have still had a background in structures; (b) are highly motivated; (c) found the SAHC program through an internet search of conservation programs around the world or the program was recommend by previous faculty or by a previous employer; (d) identified the SAHC program as uniquely dedicated to the engineering of heritage structures.

The students' previous engineering education can be classified as having dealt with "modern" engineering. For civil-structural engineers, that includes classical strength of materials, structural analyses, and design courses. Most students have had introductory courses in structural steel, reinforced concrete and possibly precast concrete. Few have been educated in the more traditional building systems such as masonry and timber construction.

Through their previous education, the student applicants have demonstrated an aptitude for many of the skills necessary to become an engineer [6]. These include: mathematical and analytical skills; logic; technical knowledge; initiative and creativity; communication and languages; professionalism and ethics; business and financial skills. At university, these aptitudes were improved through courses and training to develop more precise engineering traits [6]: problem-solving abilities; engineering skills; technical knowledge; computer skills;

inductive reasoning and critical thinking; assessment; attention to details; control precision and accuracy; team skills.

4 SA-7 INTEGRATED PROJECT

The concept of an integrated project is not new. Many international undergraduate engineering programs include a senior project or “capstone” project in their curriculum [7]. There are common characteristics of these projects in civil engineering programs: (a) they are based upon real-world projects that are usually design-based; (b) a mentor (tutor) is assigned to the project. The mentor may be a professor or a practitioner from outside the university, and will require the students interact with other faculty/experts when necessary; (c) the projects give the opportunity for the students to work across civil engineering disciplines. It is common for a project to include geotechnical, transportation, structural and environmental aspects; (d) the students function like they are on an internship, but without leaving campus; (e) the students work as a team, not individually, meaning that not all students will work on the same part of the project.

The SAHC Integrated Project is similar to a capstone project in that it represents a real-world engineering project, but with a heritage structure. Rather than a pure design project, the SAHC project is primarily an assessment project with conservation, repair and strengthening included. In many cases, a final design is produced including drawings, technical specifications, bill of quantities and cost estimation. SAHC students receive their project early in the program and it lasts for seven months. Mentors are assigned to guide the students and supplement their course work with additional lectures and site visits, as needed. The work progresses with the allocation of a few days a month in the first six months, while they are collecting competencies in different fields, and the allocation of a full week in the middle and end of the course. The Integrated Projects in each institution are discussed together three times during the course among all students and faculty, and conclude with a final presentation.

While the project tries to simulate real-world activities, the students have limited time, access and resources. This means that a realistic goal is not to create the perfect assessment of the heritage structure, or the perfect design project, but to learn the techniques, thinking processes and decision-making steps that will be encountered in the real projects they might experience in their careers after the master’s program.

4.1 Project Definition

The SAHC faculty selects several integrated projects for each university (in some cases only one project of larger complexity). The selection is usually based upon personal knowledge of the available sites or are requested from the civil society. In all cases, the structure represents a significant heritage structure for the host country. The SA-1 unit of the program provides training in historical research that is applied to the selected project.

Students are separated into teams and each team must concentrate on a major task within the entire project, or a given case study. A group’s task can include individual aspects such as conservation of materials, structural evaluation of a specific feature of the project, the assessment of the entire structure, the design of repair and strengthening, or all tasks together.

4.2 Assessment and NDT

The SA-4 unit includes inspection and diagnosis while the SA-6 unit combines conservation and restoration of materials. These units include demonstration-based classes on assessment techniques for use in the laboratory and the field. Non-destructive testing (NDT) techniques are introduced along with the associated equipment. The Integrated Project allows opportunities for students to experiment with the test equipment and techniques outside the lab environment, including state of the art techniques such as GPR testing, sonic testing or dynamic identification, and more.

4.3 Modeling and Analysis

SA-2 provides an intensive involvement in analytical methods of linear, non-linear and dynamic analyses plus graphical techniques. SA-3 introduces seismic behavior of structures. The integrated project might involve many hours of modeling and analyses to: (a) understand the current state of their heritage structure; (b) analytically validate their recommended interventions for the conservation, repair and strengthening of the structure.

4.4 Diagnosis and Assessment

SA-5 includes repair and strengthening techniques for concrete, metals, timber and masonry. Students are required to both diagnose the problems with their heritage structure and to offer interventions, as needed. Design solutions are developed for many projects. They must also assess the associated costs of their proposed interventions.

4.5 Project Conclusions

Based upon the data gathered and the analyses they perform, each team is required to arrive at conclusions on the condition of their project and provide remedial recommendations or a design solution. In some cases, they make assumptions to compensate for information that was not available. If so, the teams should make investigative recommendations for steps that could be taken to confirm their work at a later time.

4.6 Report and Presentation

The entire project is presented by each student team through oral and written presentations. Most students are not native-English speakers, but all units require formal presentation of group works to the full team of students and for the faculty involved in the course, meaning that the students develop top skills on communication and argumentation.

5 CASE STUDY - 13TH CENTURY HOUSE, PRAGUE, CZECH REPUBLIC

This SA-7 project is a very large house dating to the late 13th century near Prague Castle. Figure 1 shows an aerial view in 2011. Prague Castle and the east stairs are above the building. North is to the right. It appears in early drawings and first shows up in written records in 1407. The house was added onto several times. In 1672, it became a Theatine Monastery and functioned as such until 1883 when the monastic order was abolished. Figure 2 is a drawing from 1632 showing the east elevation.

In 1886, the building was purchased by a church and was again modified. It remained a church property until about 1950. Major repairs and strengthening were undertaken from 1945-1947 to repair damage created by vibrations from World War II German artillery stationed nearby. Under the stairs behind the building, portions of an arch of a medieval bridge were found. This arch became an interesting part of the project as well.

Figure 1 – 13th Century House, Aerial View

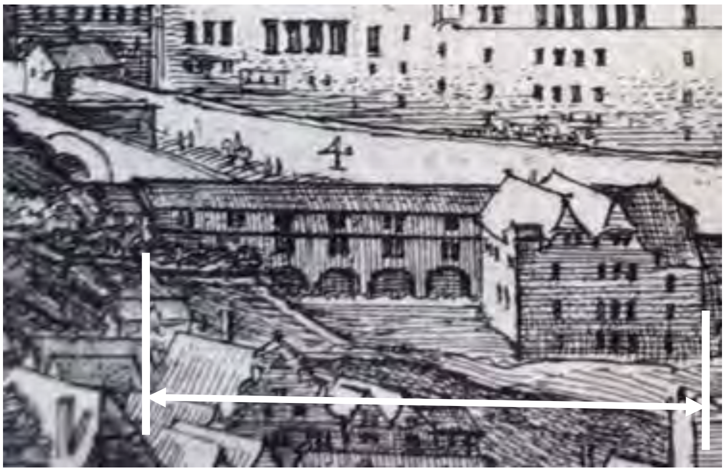

Figure 2 – East Elevation 1632

5.1 Project Assignments

Students were divided into three groups and all were required to study the history of the building. Their technical assignments included: (a) Masonry materials assessment within the building and of the exposed portions of the medieval arch. Particular study was made of the masonry deterioration within the building due to moisture deterioration resulting from water infiltration and compromises to the original ventilation system that was intended to prevent rising damp, and cracking of an arch due to structural movement and building settlement in one specific location. The medieval arch bridge had been infilled and partly overbuilt by more modern construction. The exposed portions were deteriorated from moisture and thermal effects; (b) Assessment and analysis of cracked masonry vaults in the lower floor of the building. The students were to also develop a structural monitoring system for the vaults. Historical records indicate that the artillery vibrations caused the cracking and damaged one masonry pillar; (c) Assessment and analysis of the timber roof system. Portions of the roof structure had fallen into deterioration caused by roof leaks. The main roof trusses and roof rafters had to the repaired and strengthened prior to installing a new roof.

5.2 Major Tasks

The Materials Group performed the following work: (a) Materials moisture deterioration: historical survey of air ventilation system; visual assessment of conditions; sample collection and laboratory testing for materials and moisture content; assessment of deterioration and overall building moisture (Fig. 3); evaluate possible interventions; design a building damp-proofing and ventilation system; develop cost estimates; (b) Crack assessment: site investigations; analysis of masonry arch; evaluate and propose a structural intervention; (c) Medieval arch: historical review; visual assessment; materials characterization; moisture analyses and crack assessment; evaluate possible interventions.

Figure 3 – Cross-section showing groundwater flow (left); air ventilation system (right)

The Masonry Vaults Group studied vaults in two areas of the building. The group performed material characterization; visual assessment of vaults and supports; graphical analyses of vaults as constructed; FEM analyses of current conditions; development of interventions for repair and strengthening and FEM modeling of strengthening interventions (Fig. 4); develop cost estimates.

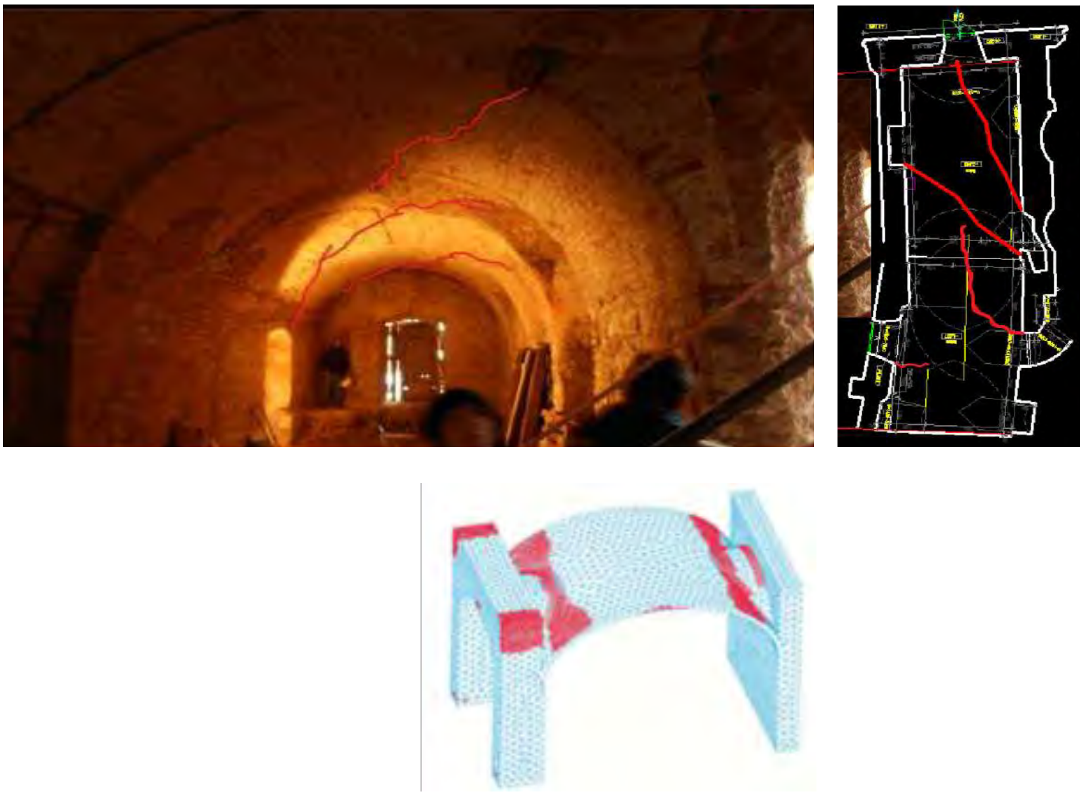

Figure 4 – Interior view of vault (left); crack mapping (right); non-linear analysis of vault to determine crack locations (lower center)

The Timber Roof Group performed an assessment of the existing timber roof in the south wing and studied possible repair and strengthening interventions. The roof system had become deteriorated from water penetration and suffered severe rotting of the ends of the trusses (Fig. 5). The students actually were able to observe the repairs during construction.

Figure 5 – Schematic of existing roof system (left); rotted ends of trusses (center); timber repairs during restoration (right)

6 CASE STUDIES – PORTUGAL

In Portugal, six SA-7 case studies were proposed to the students including the three detailed below and two others: (a) an early 20th century reinforced concrete bridge using the Hennebique system; (b) Roman masonry archaeological remains from the 6th century. In this way, the students could select subjects of their interest.

6.1 St. Vincent Church (Mentor: Dr. Graça Vasconcelos)

The Church was completed in 1694; the vault and the façade present a mix of mannerism and baroque (Fig. 6). During the 18th century, the interior of the church changed to golden baroque style and also important constructions were made. The SA-7 work included: historical research; visual inspection; damage mapping; non-destructive testing of masonry and timber, with GPR, boroscopic (endoscopy) camera, Schmidt hammer test, Pilodyn and Resistograph tests, and moisture measurement; structural analysis of roof and main vault; proposal for remedial actions and monitoring system including cost estimating.

Figure 6 – Details of the St. Vincent Church in Braga - elevation (left); damage and deterioration in the main vault (center); GPR inspection (right).

6.2 Clerigo's Church in Porto (Mentor Dr. Luís Ramos)

The Clérigos Tower (the bell tower of the Clérigos Church) is one of the paradigmatic architectural landmarks of Porto. The church was built between 1732 and 1750, but the construction works of the tower started no sooner than 1754 and was completed in 1763. It was authored by Nicolau Nasoni, the Italian architect who left a strong artistic imprint on Porto. The SA-7 objective was to evaluate the safety condition of the building (including the tower), to detect unstable phenomena, and to propose and design strengthening measures to solve the existent problems (Fig. 7). The study included: historical and geometrical survey (the team confirmed the dimensions on site and completed the survey, including the dimensions of the cross sections of the timber and masonry elements); structural identification with detailed drawings of the structural systems); damage survey, NDT, monitoring, and dynamic identification; structural analysis with modal updating and safety assessment; design of the remedial measures for the main timber floor and roof. The building was suffering important conservation works, meaning that full access was possible internally and externally, and the structural elements could be verified in details (including sections of timber beams, after removal of floor boards, and typology of masonry walls after removal of plaster).

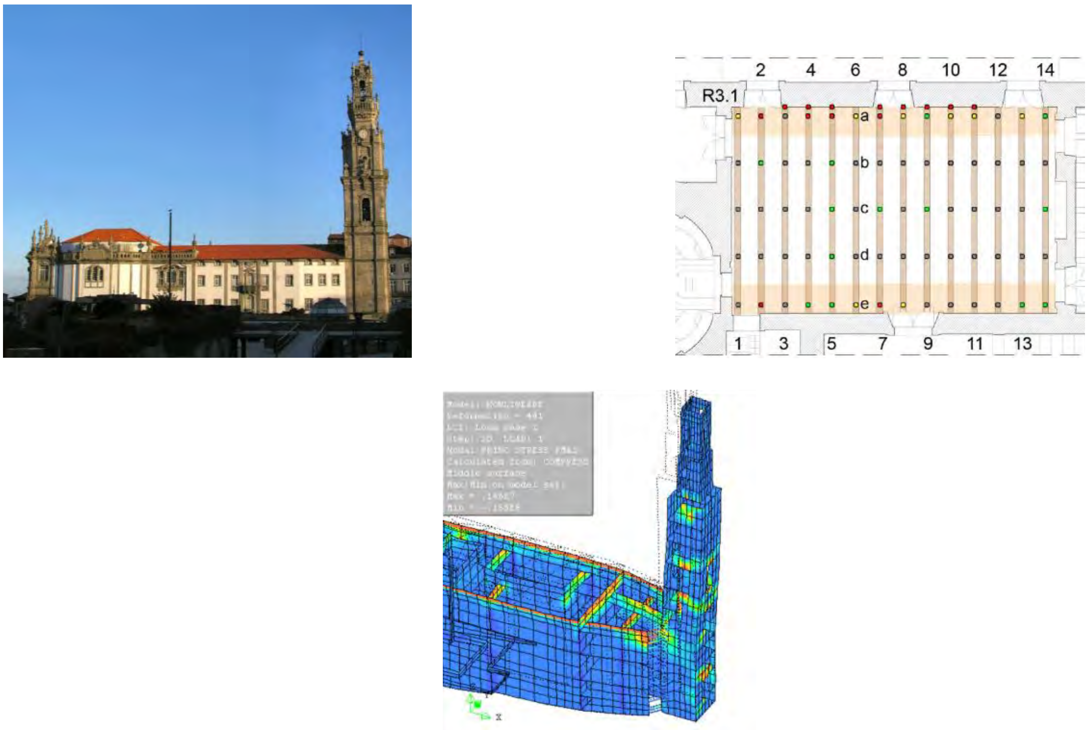

Figure 7 – Details of the Clérigo's Church in Porto: view (left); deterioration in the main floor (right); FEM model and damage predicted (lower center).

6.3 Aurifícia Company in Porto (Mentor Dr. Isabel Valente)

The Aurifícia Company is one of the pioneer's enterprises in the field of metallurgic in Portugal. Initially in 1864, it was a public enterprise, but later, in 1869 for economic reasons, it was transformed in an anonymous company with the name of Aurifícia Company. Originally, the factory was constituted by three buildings. Behind them, the complex expands in a kind of triangular shape, being functionality the main purpose. A large space with a succession of cast iron columns and trusses can be found, or a space with only the main walls of masonry that supported the trusses, with a span no larger than 6 m. The whole complex has several interesting architectural details as arches, nice staircases or large windows that allowed the entrance of light and good ventilation. The study included the following steps in the main building of the complex (Fig. 8): brief review on modern heritage conservation; historical and geometrical survey; damage survey, NDT and monitoring; structural analysis and safety assessment for the timber and masonry; definition of the remedial actions.

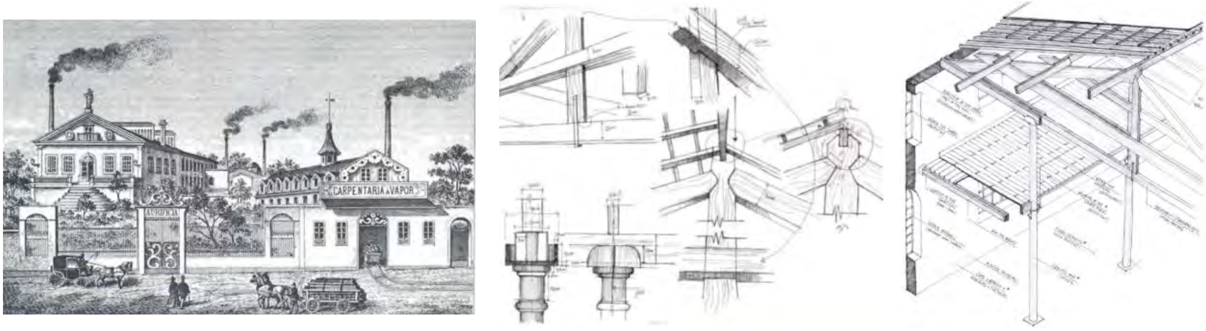

Figure 8 – Details of the Aurifícia Company in Porto: old print (left); hand drawings of some of the details (center); summary of the recommended actions (right).

6 CONCLUSIONS

6.1 Lessons Learned

After seven years of SA-7 integrated projects, many lessons have been learned that others may consider useful. These include:

<u>Benefits</u>

- The application of course work to realistic problems is useful. In addition, the community may receive a (high quality, but non-binding and liable) report and recommendations to promote restoration of the site.
- Students have interaction with government officials, owners, contractors, external consultants and experts from other fields.
- Students develop a multi-disciplinary team approach to solve difficult problems.
- There is value to experiencing a unified analysis and assessment of one structure.
- Students supplement their course work with a significant amount of self-learning to complete their projects.
- The project allows hands-on experience performing in-situ and laboratory testing.
- Preparing the final report and presentation places an emphasis on communication.

<u>Challenges</u>

- The program can be difficult for many students despite their English language proficiency. Some struggle more than others with written communications.
- Many students have little or no experience with building codes. Non-European students find the Eurocodes time-consuming to learn and understand. However, any code can be used for design and assessment.
- Students have little or no previous experience with developing construction budgets, unless they worked prior to beginning the SAHC program.
- The SA-7 project has to be programmed into the students schedule to be certain there is sufficient time to accomplish the necessary tasks and report.
- The sequence of the course units within the overall program can create difficulties to accommodate the SA-7 project, and the required knowledge. Since the units are running simultaneously with the SA-7 project, the units taught closer to the end of the course work have precious little time to be worked into the completion of the SA-7 project.

- Access to some sites is limited and students must make assumptions about unknown information or rely on third party data.

6.2 Student Reactions

Each program student completes reviews of each unit, with very good results. For the SA-7 Integrated Project, student responses have been overwhelming positive. They particularly noted the project's relevance to the course work. Comments have included a desire to greater access to the project site, earlier distribution of project data and information, and better training in cost estimation. Several noted that learning was accelerated by seeing real conditions on site. It is also the function of the team, together, to address most of the challenges detailed in the previous section. This seems a great way of preparing them to work professionally, as part of a team.

7 RECOMMENDATIONS

This discussion of the SAHC Integrated Project could result in opportunities for other universities and countries to implement such a course or to use elements of the SAHC Master program. Some basic recommendations include: (a) Select appropriate Integrated Projects that have cultural importance to the host country. The site should be readily accessible to the students unless significant technical data and background research is provided; (b) Pre-plan for the students and provide a refresher safety discussion (Insist that students use safety equipment on site and they are trained in the use of the safety equipment); (c) Assign multiple tasks that will result in a general historical review and technical assessment of the project; (d) Emphasize a team approach and good communications; (e) An important issue is that mentors responsible for the Integrated Project must have professional experience (or must team up with consultants/faculty that have good professional experience). The success of the Integrated Project lies in the professional value and not in a mere academic activity with limited linkage to practice.

Information from the SAHC program has begun some spin-off successes. The Iraqi Institute for the Conservation of Antiquities and Heritage (IICAH) in Erbil, Iraq has extended its studies to include architectural and engineering aspects rather than purely objects conservation. While there is no engineering-based program in the United States on cultural heritage structures yet, universities in New York, Vermont, Pennsylvania and others have begun offering more engineering courses in an attempt to build up an actual degree program.

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